UAS AIR TRAFFIC CONTROLLER ACCEPTABILITY STUDY-2: EFFECTS OF COMMUNICATIONS DELAYS AND WINDS IN SIMULATION

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This study evaluated the effects of Communications Delays and Winds on Air Traffic Controller ratings of acceptability of horizontal miss distances (HMDs) for encounters between UAS and manned aircraft in a simulation of the Dallas-Ft. Worth East-side airspace. Fourteen encounters per hour were staged in the presence of moderate background traffic. Seven recently retired controllers with experience at DFW served as subjects. Guidance provided to the UAS pilots for maintaining a given HMD was provided by information from self-separation algorithms displayed on the Multi-Aircraft Simulation System. Winds tested did not affect the acceptability ratings. Communications delays tested included 0, 400, 1200, and 1800 msec. For longer communications delays, there were changes in strategy and communications flow that were observed and reported by the controllers. The aim of this work is to provide useful information for guiding future rules and regulations applicable to flying UAS in the NAS.

One of the major barriers to integrating UAS in the National Airspace System (NAS) is the requirement to see and avoid other aircraft per CFR 14, Parts 91.111 and 91.113 and other applicable regulations and accepted practices. In today's operations pilots are required to follow right of way rules and remain well clear of other aircraft. There is also an obvious collision avoidance requirement. In an Air Traffic Services (ATS) environment, pilots are expected to comply with these see and avoid requirements while also complying with Air Traffic Control (ATC) instructions and clearances or to negotiate changes to these instructions and/or clearances as necessary. See-and-avoid capable pilots are generally expected to maneuver and communicate in predictable ways and in a manner that preserves the safety, orderliness, and efficiency of the ATS environment. UAS will likely be expected to operate in a similar manner, but with Detect and Avoid (DAA) replacing the see-and-avoid capability of a manned aircraft. The acceptable design space and capabilities for DAA systems in this environment are largely undefined. This controller-in-the-loop simulation experiment sought to illuminate the DAA design space for UAS operating in an ATS environment.

Detect and Avoid implementations must be designed in a way that minimizes issuance of corrective Resolution Advisories (RAs) by TCAS (Traffic Collision Avoidance System) equipped intruders. RAs are alerts with recommended vertical escape maneuvers, to maintain or increase vertical separation with intruders that are collision threats. Corrective RAs that cause evasive maneuvers can be disruptive to the air traffic system and are a last resort maneuver when all other means of separation have failed. The DAA concept evaluated in this experiment was designed to detect encounter geometries that will cause an RA, and provide guidance for action that may be taken early enough to avoid an RA.

This study is the second in the Controller Acceptability Study (CAS) experiment series and is based largely on CAS-1 experiment design, scenarios, and results. The primary goals of this study were to address the impact of communication delays and wind conditions on the execution of Ground Control Station self-separation tasks and how the resulting maneuvers are rated by Air Traffic Controllers. The communications delays used in this study include four different ATC-pilot communication latencies or delays that might be expected in operations of UAS controlled by combinations of ground or satellite command and control links. These include 0, 400, 1200, and 1800 msec one-way communications delays.

One of the goals of the earlier CAS-1 study was to establish a generally acceptable Horizontal Miss Distance when there were encounters between DAA equipped UAS and transponder equipped manned General Aviation aircraft that were not communicating with ATC. The results indicated that horizontal miss distances (HMDs) of 1.0 and 1.5 nautical miles (nmi) appeared to be optimal for ATC acceptability, when the traffic encounters are away from the airport vicinity. In that study HMDs of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 nmi were evaluated for encounters that were Opposite Direction (Head-on), Overtakes (same direction with UAS faster), and Crossings.

Objectives

The overall focus of this experiment (CAS-2) was on determining the effect of simulated DAA equipped UAS on Air Traffic Controller workload and acceptability of maneuvers with differing spacing parameters used in the DAA algorithms and with Winds and Communications delays. Based on the results of CAS-1, the set of Horizontal Miss Distances (HMD) for crossing traffic encounters was reduced to include 0.5, 1.0, and 1.5 nmi. An important difference, however, was that in CAS-1, crossing geometry HMDs of 1.5 nmi or less were designed to require no maneuver by the UAS to maintain the desired HMD. In this study, there were instances of crossing geometries of both 1.0 and 1.5 nmi that required maneuvers and concomitant communications with ATC. All opposite direction (head-on) encounters and overtaking encounters required communications with ATC and maneuvering.

Research questions

A. Given wind and communications delay conditions, were DAA self-separation (SS) maneuvers too small/too late, resulting in issuance of traffic safety alerts or controller perceptions of unsafe conditions? Tested by traffic encounters with smaller HMDs requiring maneuvers.
B. Given wind and communications delay conditions, were DAA SS maneuvers too large (excessive "well clear" distances), resulting in behavior the controller would not expect and/or disruptions to traffic flow? Tested by traffic encounters with larger HMDs.
C. Given wind and communications delay conditions, were there acceptable, in terms of ATC ratings, workload, and closest point of approach data, DAA miss distances that can be applied to the development of future DAA algorithms?
D. Do communications delays for the UAS in the airspace result in an impact on the Air Traffic Controllers communications flow? Are the delays disruptive in terms of transmissions being "stepped-on" (simultaneous transmissions by several aircraft), and/or are additional repeats of information required with delays.

Methodology

Subjects

Seven recently retired Air Traffic Controllers with experience at the Dallas-Ft. Worth (DFW) East-side facility performed traffic separation tasks for the scenarios developed. Most of the Controllers were currently instructors in the training center at DFW. Each of the controllers performed ATC tasks in the simulated DFW East side environment over two days of testing. There were 14 UAS traffic encounters each hour for six test hours and these UAS were controlled by two pseudo-pilots each having access to Ground Control Station displays showing the self-separation guidance information in real-time. Background traffic, to maintain the environment and workload close to that of actual DFW traffic, was controlled by pseudo-pilots at two additional pilot stations. Controllers who participated in CAS-1, about four months earlier, were eligible to serve in CAS-2.

Independent Variables

To get at the Research Questions noted above, the first independent variable of interest was the HMD. Related to the first variable is the encounter geometry between the aircraft in the encounter situation and the speed differentials between the encountering aircraft. Additional variables of interest include two levels of wind (calm and moderate) and four levels of communications delay. The parameters of these variables are shown in Table 1.

Table 1. *Parameters of Research Variables*

- Horizontal Miss Distances (HMD), 3 values: 0.5, 1.0, 1.5 nautical miles
- Wind Conditions, 2 values: Calm (~7 knots) and Moderate (~22 knots)
- Communications Delay, 4 values: 0, 400, 1200, and 1800 msec (one-way times)
- Encounter Geometry, 3 cases: Opposite-direction, Overtake, Crossing
    - Intruder Opposite-direction at 180 degrees +/- 15 degrees (Non-crossing)
    - Intruder at 90 degrees +/- 15 degrees (Crossing)
    - Intruder ahead at 0 degrees +/- 15 degrees (Overtaking, Non-crossing)
    - All geometries without vertical separation (but may include climbing/descending trajectories)
    - UAS requests passes to right of intruder for non-crossing geometries
    - UAS passes in front of intruder for crossing geometries
    - Intruder Speed Differential (5 values for Crossings: 0, +/- 40, +/- 80 knots)
- 42 test conditions: 6 Opposite-direction, 6 Overtake, 30 Crossing
- 14 encounters per hour, 6 hours of testing over two days, 84 total encounters
- Background (non-encounter) traffic communicating with ATC: Approximately 40 per hour

Scenarios

The airspace modeled for this experiment is a portion of airspace delegated to Dallas-Ft. Worth TRACON (D10). Specifically, Sector DN/AR-7 South Flow. The majority of UAS traffic arrived or departed the Collin County Airport (KTKI). The scenarios were designed and situated in this airspace so as to enable various encounter geometries between the UAS and intruder aircraft while manned aircraft traffic was handled in order to achieve realistic levels of workload for the Controllers. A chart of the area is shown in Figure 1.

Communications, Navigation, and Surveillance Assumptions

The experiment assumed Communication, Navigation and Surveillance (CNS) architectures and capabilities appropriate for current-day operations in the applicable airspace classes and that these capabilities were available to all aircraft (manned and unmanned) in the simulation environment. The intruders were not communicating with ATC. UAS command, control, and communication capability was assumed available between Unmanned Aircraft (UA) and their respective GCS. The UA was assumed to be capable of receiving/transmitting voice communications to and from ATC facilities and proximate "party-line" aircraft via VHF frequencies in the same manner as manned aircraft in the same airspace, and of relaying these voice communications to/from the GCS pilot via one or more UA-GCS links. It was further assumed that, in addition to the relayed voice communications, the UA-GCS link(s) carried all command/control data between the UA and GCS. This study assumed large UAS. The UAS GCS pilots were confederate participants (not subjects). It was assumed that surveillance sensors applicable to support SAA were available and functioned without failures.

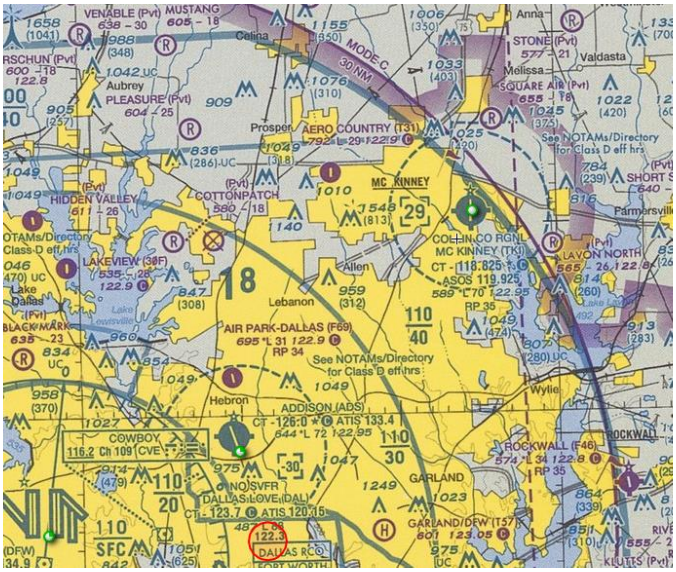

Figure 1. Chart showing Collin County Airport (McKenny, KTKI), upper right; DFW is in the lower left.

Facilities, Software, and Hardware

The study was run in a dedicated facility housed at Stinger Ghaffarian Technologies (SGT), near the NASA Langley Research Center. The displays for the UAS and manned aircraft control stations and the ATC displays were driven by modified versions of the MACS (Multi Aircraft Control System) software (Prevot, 2002). Modifications included incorporation of Stratway+ algorithms to drive Navigation display "bands" which indicated a range of headings that would result in a loss of well clear with one or more traffic aircraft. Information on the self-separation algorithms may be found in Hagen, Butler, and Maddalon, 2011, and Muñoz, Narkawicz, Chamberlain, Consiglio, and Upchurch, 2014. The hardware, software, and operations implementation team included personnel from SGT, Adaptive Aerospace Group (AAG), and Intelligent Automation Inc. (IAI).

Dependent Variables

Horizontal Miss Distance Ratings. After each traffic encounter, an ATC subject matter expert seated next to the Controller subject asked: "How was the spacing of that last encounter?" or "How Acceptable was the miss distance in the previous encounter?" Subjects had a copy of the information in Table 2 available to them during the test sessions. They were briefed that fractional responses, such as 1.5 or 3.5, were completely acceptable. If time permitted, an explanation for the rating was asked and noted.

Table 2. *Rating scale used for encounter assessment. (Fractional values, e.g., 1.5, were acceptable)*

1	Much too close; unsafe or potentially so; cause or potential cause for issuance of a traffic alert
2	Somewhat close, some cause for concern
3	Neither unsafely close nor disruptively large, did not perceive the encounter to be an issue
4	Somewhat wide, a bit unexpected; might be disruptive or potentially disruptive in congested airspace and/or with high workload
5	Excessively wide, unexpected; disruptive or potentially disruptive in congested airspace and/or with high workload

Workload assessment. About every five minutes during each hour long test session a workload rating was requested. This was done similar to the ATWIT (Air Traffic Workload Input Technique) method of Workload assessment (Stein, 1985). A scale with numbers from 1 to 6 was presented at the top of the ATC display and the subject clicked on one of the numbers when an aurally presented (through headphones) "Ding" occurred and the rating scale turned yellow. ATC Test subjects were briefed on definitions of the 1 to 6 scale during training and also had the scale definitions available during the test sessions. For this study the scale definitions were: 1 - Minimal mental effort required; 2 - Low mental effort required; 3 - Moderate mental effort required; 4 - High mental effort required; 5 - Maximal mental effort required; and 6 - Intense mental effort required.

System Performance Metrics. Data concerning the encounter aircraft were recorded and included Aircraft-to-Aircraft separation distances and time to the closest point of approach (CPA). For the communications time delay conditions, the communications system that permitted incorporating delays also recorded the push to talk status of all parties communicating so that "step-ons" (two stations transmitting at the same time) could be recorded.

Post-run questionnaires. After each one-hour test session a questionnaire was administered to record ratings and comments on the preceding test session. Specific topics addressed included: 1 – Effects of communications delay; 2 – Realism of traffic density; 3 – Realism of workload; and 4 – Realism of communications rate.

Results

Horizontal Miss Distances. Figure 2 shows the mean ratings by the Controllers for each of the Horizontal Miss Distances (HMDs) tested for the crossing traffic encounters. The Geometric CPA (Closest Point of Approach) is how close the two aircraft would pass if no maneuver was made. If HMD was equal to Geometric CPA, no maneuver would be called for by the self-separation algorithms, and no communications with ATC to request a maneuver was required. To see if the Controller's rating was affected by whether the UAS had to contact ATC to request a maneuver to maintain the HMD, the encounter geometry was also set up such that the HMD was greater than the Geometric CPA for the 1.0 and 1.5 nmi HMDs. As can be seen from Figure 2, the Controllers ratings of HMD were not affected by whether communications and a maneuver were required by the UAS.

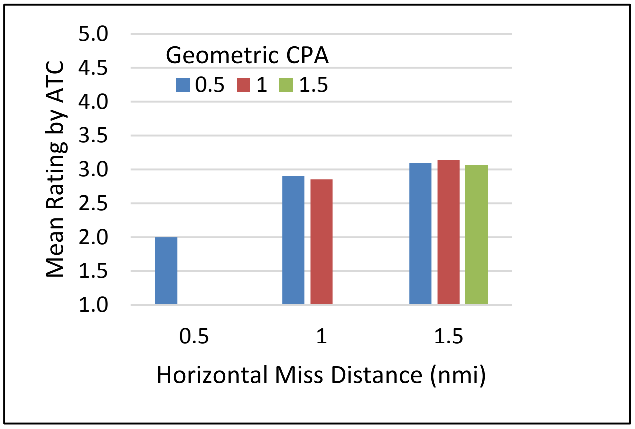

Figure 2. Mean Ratings by encounter distance (Crossings). Rating definitions are in Table 2.

Figure 3 shows the Controller rating data for crossing encounters and shows the highest percentages for a rating of 3 (*Neither unsafely close nor disruptively large, did not perceive the encounter to be an issue*), at the 1.0 and 1.5 nmi HMDs. Ratings shifted for the 0.5 nmi HMD indicating greater concern for that miss distance. Figure 4 shows similar rating data for the Overtake and Opposite Direction encounters, all of which required maneuvers, and communications with ATC. The rating scale used is shown in Table 2.

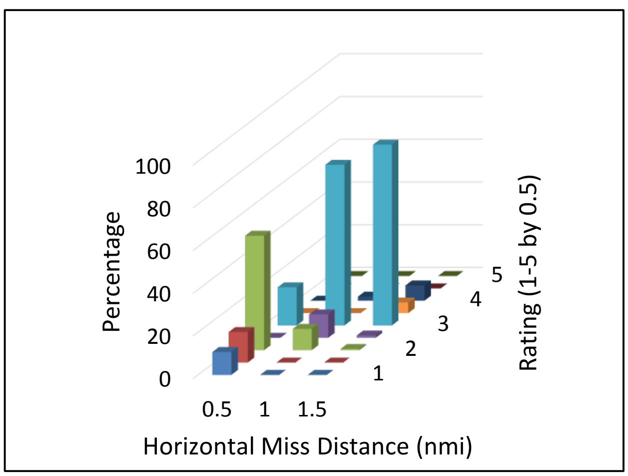

Figure 3. Ratings by HMD (Crossings)

Realism of Traffic Density and Workload. Care was taken in the design of the research scenarios to have traffic densities like those found in the real world. In response to the end of each hour question "*Rate the realism of the Traffic Density of the simulation during the preceding hour,*" 66.7% of responses were that "*Traffic Density was about the same as would be found in real world operations;*" and 31.0% of the responses were that "*Traffic Density was somewhat lower than real world operations*." Workload ratings, based on data collected at 5-minute intervals, showed the following distribution of responses: 32.3% "*Minimal mental effort required;*" 42.9% "*Low mental effort required;*" 18.2% "*Moderate mental effort required;*" and 0.9% "*High mental effort required*." Workload ratings did not differ across the two wind levels or four communications delay conditions.

Communications Delays and Wind. Communications delays of 0, 400, 1200, and 1800 msec (one-way times) were used for communications with the 14 UAS per hour that had traffic encounters. Manned aircraft in the scenario had no added delays. While no differences in ratings of HMD or workload were noted, selected Controller comments reflect the difficulties long delays introduce: "*The communications delays did cause some a/c to 'step-on each other.' This required extra transmissions to other traffic because they were blocked;" "The delay resulted in many repeats and was irritating;" "Repeats have a major impact on workload of ATC. In a busy environment you can't stand for a lot of them;" "Numerous repeats and step-ons! When in busy environments your transmissions need to flow and repeats/blocks only put you behind.*" Also observed was a change in strategy by some controllers in the long delay scenarios to work manned, quicker responding, traffic first then go to the UAS with their delayed responses. The "low" and "moderate" wind levels did not create any issues for the controllers. For the UAS pilots the separation algorithms handled the wind conditions with no problems.

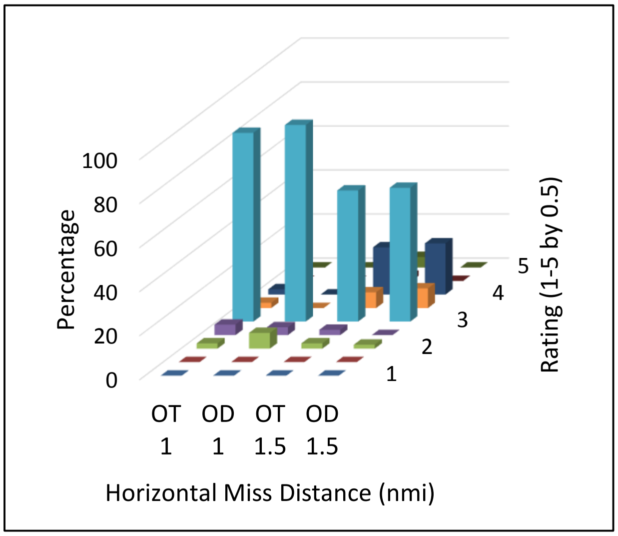

Figure 4. Ratings by HMD (Overtake – OT and Opposite Direction - OD)

Discussion

The present study employed a simulation of the Dallas-Ft. Worth East-side airspace with UAS operating in and out of Collin County airport Northeast of DFW. The results confirm the Controller acceptability of 1.0 and 1.5 nmi HMDs found in the CAS-1 study, even when maneuvers are required to maintain those miss distances, and winds are part of the scenarios. The 7 and 22 knot wind conditions tested were handled by the self-separation algorithms without issues, and presented no issues for the controllers. Long voice communications delays between the UAS and ATC are identified as a problem in a high traffic-density environment such as this.

Since the present study assumed perfect surveillance, future studies should incorporate sensor uncertainty and sensor effective range as variables of interest. Also of interest are simulation of failure modes, and especially from the ATC perspective, the maneuvers that a UAS would perform in a high traffic density environment if the communications link is lost. The aim of this work is to provide useful information for guiding future rules and regulations applicable to flying UAS in the NAS.

References

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